Draft CEC PIER-EA Discussion Paper

Ecology and Adaptation

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Disclaimer

The purpose of this paper is to inform discussions among CEC staff, other state agency staff, non-governmental representatives, representatives of academia and other stakeholders regarding the state of the research on ecological impacts and adaptation in California. In particular, this discussion paper will identify gaps in our understanding and recommendations for future research initiatives with the end goal of supporting informed and systematic planning for climate change. Note that this paper is not intended as a research proposal and should not include recommendations regarding specific researcher projects.

1.0 Description of Research Topic

Current climate impacts on California species and natural systems

California's terrestrial, fresh water, and marine habitats face an uncertain climatic future. Although climate has changed repeatedly over past millennia, for a variety of reasons (Houghton et al., 2001), anticipated human-driven changes are likely to be unusually fast and large. Many of California's species and ecosystems are particularly vulnerable to future climatic change, because their current ranges are limited and their potential ranges are bounded by the coast or other topographical features (Snyder et al., 2002). And California's unique mediterranean climate (hot, dry summers and cool, wet winters) under which its ecological systems evolved is projected to change dramatically. Mean annual temperatures in California have already increased by 1˚C between 1950 and 2000 and are projected to increase by another 2 to 4˚C before 2100 (Christensen et al., 2007; LaDochy et al., 2007). These contemporary climatic changes have had a demonstrable impact on California's natural resources. Droughts have become more severe over the last 100 years, especially in the southern part of the state, a trend that is projected to continue over the next 100 years (Christensen et al., 2007; Seager et al., 2007; Trenberth et al., 2007). Species are shifting ranges, abundances, and timing of phenology. In one study in California, 70% of 23 butterfly species studied advanced the date of first spring flights by an average 24 days over the period from 1972 to 2002 (Forister and Shapiro, 2003) with climate warming during spring as the single most influential factor. Scientific researchers have documented current and projected changes in species distributions and phenologies, community composition, rare or sensitive ecosystems, and have begun to explore the implications of these changes for the provisions of ecosystem services (*sensu* Millennium Ecosystem Assessment, 2005).

Committed to climate change

Even now, California is committed to continued human-driven climatic change and more impacts, with or without societal interventions (Kerr, 2004, 2005). In addition, there is much uncertainty regarding the impact and the trajectory of future climate change as it is highly dependent on the greenhouse gas emissions pathway in the future (Houghton et al., 2001; Hayhoe et al., 2004). These uncertainties are reflected in the wide range of projected temperature and precipitation changes for California because of its topographic relief and its high latitude. In California this century, the average annual statewide temperature is projected to rise 1.7 – 3.0˚C (3.0– 5.4˚F) under low emission scenarios and 3.8 – 5.8˚C (6.8 – 10.4˚F) under higher emissions scenarios (Hayhoe et al., 2004; Cayan et al., 2006). The projections for statewide annual average precipitation change range from a decrease of 157 mm to an increase of 38 mm (Hayhoe et al., 2004; Cayan et al., 2006), with significant variation in projections among GCMs and emissions scenarios (Pan et al., 2001; Salathe, 2003; Wood et al., 2004). It is also the case that additional stresses to California's species and ecological systems are likely to come from increased invasions from non-native species, more frequent fires, unforeseen interactions between species as the climate shifts, and natural and non-natural barriers to migration (Suttle et al., 2007). Under pressure from climate change and the full array of stressors, these ecosystems, including the distinctive species associated with these places, will necessarily respond and change. Thus it is likely that California's species and ecosystems, and the direct value we derive from them via ecosystem services (e.g., sustain biodiversity, promote clean water, and sequester carbon), will also be altered dramatically.

2003 PIER Research Plan

In the 2003 PIER Research Plan, the goals were to improve the state-of-science/art regarding climate change and its physical and economic impacts on California, and produce policy relevant research that will allow the state to develop sound mitigation and coping strategies. As such, the ecological research questions focused on projecting impacts of climate change on vegetation patterns, and subsequent changes in ecosystem services (e.g., *What are the potential changes in vegetation patterns in California, and how would they affect and be affected by the state's climate and the hydrological cycle*?), and understanding how other stressors will impact vegetation distribution in a changing climate (e.g. *How would urban development and climate change affect vegetation patterns in California? Would urban areas impede the migration of species, and therefore be a dominant feature determining vegetation patterns?*). These goals were intended to highlight impacts and, therefore, intervention opportunities for adaptation.

Reframing adaptation from describing impacts to designing resilience

With this range of uncertainty in future climatic impacts and the persistence of other stressors, it will be important that the PIER-EA-funded adaptation research go beyond the systematic identification of potential future ecological impacts under a narrow set of future climatic conditions for understanding system vulnerabilities, and therefore, adaptation options, to a much more comprehensive analysis of vulnerability (see Adaptation and Vulnerability Report by Moser). The current "impacts" approach to understanding vulnerability is necessarily passive and assumes that adaptation is in reaction to experienced impacts only. Alternatively, the goal of adaptation should be increasing the long-term resilience of California's natural and managed systems by increasing the adaptive capacity of the managing institutions. To do this, research will need to be designed to understand the range of potential future climate changes, the uncertainties associated with those ranges, the degree of exposure and sensitivity of particular species or systems to the full range of climatic change, the synergistic impacts of other factors that might alter exposure or sensitivity to climatic changes (e.g., land use change), and the adaptive capacity for resource management institutions to respond to and reduce vulnerability given current goals and institutional mandates.

This reframing of adaptation research for ecological systems in California will allow for a systematic analysis of the institutions that manage California's natural resources, the factors that make California's species and natural resources vulnerable to impending climate change and the identification of institutional changes to enhance resilience. Proactive measures to address climate change impacts have proven to be more cost-effective and efficient than reactive measures (e.g., Schneider et al., 2000; Easterling et al., 2004). With concerted planning for adaptation, adaptation measures can be implemented in the course of short-term operational and longer-term strategic planning and management decisions (Paavola and Adger, 2002; Luers and Moser, 2006).

2.0 Summary of PIER Program Research to Date on Ecology and Adaptation

PIER-funded research on ecology and adaptation has largely been focused on current and projected impacts of climate change on species distribution, vegetation distribution with specific emphasis on forestry (see Forestry Report by Robards), and the impact of the vegetation distribution change on water resources. Research on vulnerability and adaptation has been limited to date (see discussion on Adaptation and Vulnerability report by Moser). This report will cover all PIER-funded projects focused on current and projected impacts of climate change on the distribution of non-forest species and systems within two funding programs: Climate Change Grants and Environmental Exploratory Grants.

Climate Change Program

- *Global Climate Change and California: Potential Implications for Ecosystems, Health, and the Economy*. Wilson. (Available at http://www.energy.ca.gov/reports/500-03-058/2003-10-31_500-03-058CF.PDF). This study looked across multiple sectors to explore the synergistic impacts of climate changes. The study found that the location of natural vegetation will change dramatically, productivity could increase under wetter conditions and biodiversity could be reduced under drier conditions. The combined effects of climate change and urbanization on vegetation could adversely affect some critical systems. Timber production may initially increase and then decrease, but producers and consumers may be more affected by changes in global timber prices.

- *A Review of Land Use/Land Cover and Agricultural Change Models (*Available at *http://www.energy.ca.gov/2005publications/CEC-500-2005-056/CEC-500-2005-056.PDF).* This review summarized many of the leading land use/land cover change models being used to predict urban/rural land use change, as well as those more specific to agricultural land use change. This assessment was conducted to examine model differences and assess which models may be most appropriate for use in Public Interest Energy Research (PIER) Climate Change studies. This report provided an overview of the models examined, a brief assessment for their usability in the PIER project, and a comparison chart of select factors of the models examined. Of the 39 leading land use/land cover change models examined, only 11 met the criteria established for use in the PIER climate change and ecosystems project. The report recommended use of the California Urban and Biodiversity Analysis Model (CURBA) as the most appropriate model to use in the PIER Climate Change studies.

- *The Response of Vegetation Distribution, Ecosystem Productivity, and Fire in California to Future Climate Scenarios Simulated by the MC1 Dynamic Vegetation Model.* Lenihan (USFS). (Available at www.energy.ca.gov/2005publications/CEC-500-2005-191/CEC-500-2005-191-SF.PDF) Lenihan et al. (2006) conducted a modeling exercise to understand biome shifts in California under a changing climate over the next 100 years. Building on previous PIER-funded dynamic vegetation model (DVMs) work, this project explored ecosystem responses to multiple global changes and identified trends that would affect California. The study evaluated the effects of land use (e.g., the impacts of current land use, land use change, land cover fragmentation, the history of land management on ecosystem dynamics, and migration corridors); vegetation age structure; species dispersal rates and modes (for a few target species); fire; and non-native invasive species and introduced pest pathogens to investigate the interaction between climate and vegetation. The objective of the study was to "dynamically simulate the response of vegetation distribution, carbon and fire to three scenarios of future climate change for California using the MAPSS-CENTURY (MC1) dynamic vegetation model, driven by climate output from two GCMs (Bachelet et al., 2001; Lenihan et al., 2003; Lenihan et al., 2006). Lenihan et al. projected broad scale changes in vegetation distribution. (See detailed description of impacts in Section 3.1)
- *Predicting the Effect of Climate Change on Wildfire Severity and Outcomes in California: A Preliminary Analysis.* Fried. (Available at www.energy.ca.gov/2005publications/CEC-500-2005-196/CEC-500-2005-196-SF.PDF). This paper focused on how climate change-induced effects on weather will translate into changes in wildland fire severity and outcomes. Prior research indicated that there is a potential for significant increases in the number of fires escaping initial attack driven primarily by predicted increases in wind speeds. The results of this study indicated that subtle shifts in fire behavior of the sort that might be induced by the climate changes anticipated for the next century are of sufficient magnitude to generate an appreciable increase in the number of fires that escape initial attack, at least for areas where brush fuels dominate.

Environmental Exploratory Grants Program

- *Corridor Effects on the Endangered Plant Kern Mallow and Its Habitat*
- *Development of 70-Year-Old Wieslander Vegetation Type Maps and an Assessment of Landscape Change in the Central Sierra Nevada*. James Thorne (UC Davis). Completed 5/07. (Available at http://www.energy.ca.gov/pier/final_project_reports/CEC-500-2006-107.html) This project made use of historical data from the Wieslander Vegetation maps, plus modern resurvey data, to understand trailing Edge Dynamics for a Ponderosa Pine Forest in the Sierra Nevada, CA. In the 1930s, a U.S. Forest Service team led by A.E. Wieslander surveyed California's vegetation over roughly one-third of the state, producing a rich data set including vegetation

type maps, thousands of photographs, and 25,000 herbarium specimens. This historical data enabled researchers today to assess vegetation changes over the interim (Thorne et al., 2006). In a study of ponderosa pine forest changes between 1934 and 1996 on the western edge of the Sierra Nevada (Placerville Quadrangle), researchers found that the western edge of the forest moved an average of 7.1 km eastward and shifted upward by about 193 meters. Previously ponderosa-dominant areas were replaced by non-conifer species. Thorne et al. (2006) found an increase in monthly minimum temperatures in the middle-elevation Sierra Nevada Mountains over the past 100 years by about 3ºC (5.4ºF) which correlates with longer summer drought conditions, which in turn increase drought stress on seedlings. The area was likely affected by synergistic stressors such as fire, urbanization, and cattle grazing.

- *Global Warming and Breeding in Migratory Birds: Utilizing an Undervalued Historic Database:* Terry Root (Stanford University). (Available at www.energy.ca.gov/2007publications/CEC-500-2007-010/CEC-500-2007-010.PDF) Spring and fall migratory phenology in California were analyzed to investigate whether changes in migratory phenology (e.g., earlier or later arrival) are occurring. Earlier spring and autumn migratory phenology is occurring along the coastal Pacific flyway. The multi-site analysis provides greater evidence that changes in western North American land ecosystems are already detectable with warming of less than a degree Celsius over the past century.

3.0 PIER Accomplishments

The 2003 PIER Research Plan goals were to improve the state-of-science/art regarding climate change and its physical and economic impacts on California, and produce policy relevant research that will allow the state to develop sound mitigation and coping strategies. Under these goals, the ecological and adaptation research questions were narrow and modest in their scope, and included:

- What are the potential changes in vegetation patterns in California, and how would they affect and be affected by the state's climate and the hydrological cycle?
- How would urban development and climate change affect vegetation patterns in California?
- Would urban areas impede the migration of species, and therefore be a dominant feature determining vegetation patterns?

Lenihan et al. (2006) addressed the first research question: *What are the potential changes in vegetation patterns in California, and how would they affect and be affected by the state's climate and the hydrological cycle?* Lenihan et al. (2006) projected broad scale changes in vegetation distribution under all three emissions scenarios. Grassland total percent cover increased by >65% under all future climate scenarios. Grasslands and shrublands were both initially favored by the increase in moisture under future climate scenarios, but increases in grass biomass produced more fine flammable material that promoted a higher frequency of fire, resulting in the expansion of grasslands (Lenihan et al., 2006). All scenarios also showed >60% declines for alpine/subalpine forest cover, >30%

declines for shrubland, and >20% decline for mixed evergreen woodland. Only grasslands and mixed evergreen forest increased in total percent cover. Fire played a critical role in major biome shifts by either by slowing encroachment of shrubland into grasslands under high precipitation scenarios or increasing the rate of transition of woody biomes to grasslands under low precipitation scenarios. While none of the simulations by Lenihan et al. (2006) can be interpreted as predictions of the future vegetation distribution, they provide important insight into direct and indirect feedbacks that will influence biome and biodiversity distribution under a changing climate, and provide the opportunity for resource managers to begin to explore what it will mean to manage for achieving today's goals under this degree of change.

Wilson et al. (2006) addressed the second two questions: *How would urban development and climate change affect vegetation patterns in California and would urban areas impede the migration of species, and therefore be a dominant feature determining vegetation patterns?* The Wilson team developed a research process to systematically address the first, but not the second half of the research question. The Wilson et al. (2006) study was designed to help California natural resource managers and other policy makers better understand the potential effects of the interacting stressors of climate change and urban development on the state's biodiversity. The goal of such work is to quantify the impacts of climate change for California and make available information that natural resource managers can use to develop adaptation policies and practices.

They used two population scenarios, and two global circulation models under three emissions scenarios. Using the Lenihan (2006) results of ecosystem change, they demonstrated the migration of forests and other types of vegetation to higher elevations as warmer temperatures make those areas more suitable for survival; as it gets wetter, forests would expand in northern California and grasslands would expand in southern California. If it gets drier, areas of grasslands would increase across the state. They then combined these results with the estimated future urbanization patterns to examine relative effects of climate change and urbanization on biodiversity. While urbanization slightly reduces the diversity of vegetation communities across the state, all vegetation types were much more significantly affected by climate change. The study found that the warm and wet climate could result in little change or even an increase in diversity of community types; a warm and dry climate could reduce community diversity much more than would urbanization. For habitats already strongly affected by urbanization at a local scale, such as the species-rich coastal sage scrub which has been reduced to 10% of its original extent, only a very small fraction of that would persist under a changing climate and future development.

This study was valuable for identifying future macro trends in habitat distribution under climate change and its interaction with human development patterns. The study showed that combination of urbanization will be catastrophic to some of the State's biodiversity. The study did not effectively address the biodiversity impact of climate change and urbanization because it focused potential changes in habitat types and not species. The study did not effectively address whether urbanization would impede migration of species.

4.0 Non-PIER Accomplishments in this Area and Opportunities for Collaboration

Observable responses to climate change

There are observable impacts of climate change on terrestrial ecosystems in North America including changes in the timing of growing season length, phenology, primary production, and species distributions and diversity (Walther, 2002; Parmesan, 2003; Peñuelas and Filella, 2001; Fields, 2007; Parmesan and Yohe, 2003; Root et al., 2003, 2005; Parmesan, 2006). Currently, spring is beginning earlier, while the arrival of autumn is being delayed (Menzel et al., 2006). Change in seasonal timing has serious implications for the life cycles and competitive abilities of numerous species (Walther et al., 2002; Visser and Both, 2005; Parmesan, 2006). Examples of different ecological effects in Europe and North America include shifts in spring events such as budburst, floral abundance egg laying, bird migration, and the hatching of caterpillars occurring earlier over the course of the last 30 years (Menzel et al., 2006; Schwartz et al., 2006; van Asch and Visser, 2007; Inouye, 2008). In California, 70% of 23 butterfly species advanced the date of first spring flights by an average 24 days over the period from 1972 to 2002 with climate warming in the spring the single most influential factor (Forister and Shapiro, 2003). In an analysis of 866 peer-reviewed papers exploring the ecological consequences of climate change, analyses of field-based phenological responses have reported shifts as great as 5.1 days per decade (Root, 2003) with an average of 2.3 days per decade across all species (Parmesan, 2003).

Using observed species data, Schneider and Root contend that human activities have contributed significantly to temperature changes, and human-changed temperatures are associated with discernible changes in plant and animal traits (Root, 2005). Evidence from two meta-analyses (143 studies, Root, 2003; 1700 species, Parmesan, 2003) and a synthesis (866 studies, Parmesan, 2006) on species from a broad array of taxa suggests that there is a significant impact of recent climatic warming in the form of long-term, large-scale alteration of animal and plant populations (Root, 2006; Parmesan, 2003; Root, 2003). As we are now able to measure ecological signals above the background of ecological variation for a temperature increase of 0.6° C, the expected impacts on species and ecosystems of temperature increases up to an order of magnitude larger by 2050 are sure to be dramatic (Root, 2006).

Observable change in species distribution and abundance

Movement of species in response to climate warming is expected to result in shifts of species ranges poleward and upward along elevational gradients (Parmesan, 2006). Species differ greatly in their life-history strategies, physiological tolerances, and dispersal abilities which underlies the high variability in detecting species responses to climate change. A few studies have been conducted at a scale the encompasses an entire species' range (amphibians, Pounds, 1999, Pounds, 2006; pikas, Beever, 2003; birds, Dunn, 1999; and butterflies, Parmesan, 2006, Parmesan, 1996). There is a growing body of evidence that have inferred large shifts in species range across a very broad array of taxa. In an analysis of 866 peer-reviewed papers exploring the ecological consequences of climate change, nearly 60% of the 1598 species studied exhibited shifts in their distributions over the 140 year time frame (Parmesan, 2003). In California where many ecosystems are highly sensitive to the influence of temperature and water availability, increasing temperatures, changing precipitation patterns, and declining soil moisture trends have shifted the suitable range for many species typically to the north or to higher elevations (Parmesan and Yohe, 2003). Indeed, Kelly and Goulden (2008) compared surveys of plant cover that were made in 1977 and 2006–2007 along a 2,314-m elevation gradient in Southern California's Santa Rosa Mountains and found that the average elevation of the dominant plant species rose by 65 m between the surveys. The altitudinal shift is attributable to increases in surface temperature and in the precipitation due to climate change.

Modeled changes in species distribution

There has been an explosion of studies in the last five years projecting impacts on species distribution under an array of climate change scenarios. In a study of 120 native mammals in Europe, researchers found that widespread species do not experience the same conditions as endemics (Levinsky et. al., 2007). Endemic species experience a gain between 45-48% in climatically suitable area under a universal migration assumption while widespread species gain only for 23-25%. In addition, endemic species were found to be more vulnerable to climate change under a no-migration assumption than the widespread species considered, probably due to their smaller distributions (Schwartz et al., 2006). A new study that modeled the controls on California oak regeneration as affected by climate change finds that successful regeneration of oaks is linked to climate and "reserved" status of the population, suggesting that species dispersal will be an important determinant of regenerative ability in a changing climate (Zavaleta, Hulvey, and Fulfrost, 2007). The critical role of dispersal was similarly highlighted in a much broader study which modeled ranges for over 500 endemic plant species 80 years from the present (Loarie et al., 2008). These researchers observed decreases in biodiversity under a higher-emissions scenario (a loss of about 1 species per acre), but found that increasing the species' dispersal ability buffered against species losses. At a lower emissions scenario (B1) and high dispersal capability, biodiversity actually increased in many areas of the state (Loarie et al., 2008).

Aquatic systems

Although very few studies address climate impacts on fresh water ecology and species distribution, it will be important to address these impacts and vulnerabilities in the future. Salmonids have been the focus of many ecological studies on the impact of aquatic diversity. Although more locally specific research on the impacts of climate change on salmon is still needed for California, research conducted in the Puget Sound area of Washington state shows that the modeled population of salmon will be negatively impacted by climate change, largely due to the reduction in snowpack and hence runoff during important stages in the salmon's lifecycle, as well as increases in water temperature (Battin et al., 2007). In this study, salmon populations declined 20-40% by 2050, depending on the model used. The two primary reasons for this decline were the climate change-induced reduction in suitable cold-water habitat and reduced stream flows for salmon spawning, incubation, and rearing (Battin et al., 2007). These findings suggest that climate change impacts to California salmon should be a high priority for future research.

To ensure persistence of California's unique natural heritage and facilitate adaptation in the face of climate change, it is important to lay out a research agenda that not only identifies contemporary impacts on the distribution and abundances of species, but evaluates those impacts in the context of contemporary climatic change, and potential future distributions in the context of multiple stressors including landscape context, and evaluates opportunities for adaptation given current institutional management goals.

5.0 Research Underway/Committed to via PIER Process

Global Climate Change Program

- *Dynamic Ecosystem Modeling for California.* Lee Hannah (Conservation International). BioMove was intended to advance beyond process-based ecosystem models to project the impacts of climate change on individual species within a region's flora and fauna, by incorporating biotic and dispersal. The BioMove model was used to assess climate change effects on endemic plants and plants of conservation interest in California. 300 California plant species, including 89 endemics were analyzed. In this study, the majority of species modeled retained more than 60% of their present range up to 2050 in all scenarios. By 2080, range shifts were more pronounced and over 30% of species lost most of their range under the highest emission scenario. Patterns in overall richness of endemic species were similar between the present and 2050 scenarios, consistent with the modest changes in individual species. In 2080, peak endemic richness declined in all scenarios. Individual range shifts were idiosyncratic, a trend consistent with other range modeling studies for California and elsewhere. Some species gained range in the high Southern Sierras, resulting in a net southward range shift, the opposite of the general pattern of northward range shifts. Similar countervailing range shifts have been observed in South Africa and other regions where topography is sufficient to override latitudinal trends. Broadleaf plant functional types gained at the expense of needleleaf functional types, confirming a pattern seen in DGVM modeling for California. Oaks as a group gained more range than they lost, while pines did the reverse, losing more range then they gained. Many of the needleleaf losses were in areas in which broadleafed types expanded.

Environmental Exploratory Grants Program

- *Ecosystem Feedbacks to Climate Change in California: Integrated Climate Forcing from Vegetation Redistribution.* Lara Kueppers (UC Merced). This study used a regional climate model to estimate the relative importance of climate-ecosystem feedbacks to predictions of future climate change in California, with a particular emphasis on the role of native ecosystem shifts and regions proposed for afforestation. The project synthesized available predictions for changes in the geographic distribution of ecosystems resulting from climate change and afforestation. Initial results show that shifts in the distribution of ecosystems substantially alter near surface afternoon temperatures. Some parts of the state were more strongly affected than others. For example, in the northern Central Valley, grassland expansion into what had been conifer forests resulted in increases in annual mean midday temperatures up to 1.5°C in the converted areas, with the most pronounced change (up to 2.5°C) in mid-summer. Where conifer forest expanded into woodlands in northern California, July midday near-surface air temperatures declined by up to 1°C. These results suggest that climate-driven shifts in the distribution of California's ecosystems can amplify local and regional climate change.

- *Measurement of Large-Scale Gene Flow: A Pathway to Understanding Adaptation and the Genetics of Climate Tolerance.* Jessica Hellman (University of Notre Dame). (Available at http://www.energy.ca.gov/publications/%0BdisplayOneReport.php?pubNum=CEC-500-2007-043.) This research project tested critical assumptions about the genetic differences between populations in California, differences that may determine the ecological responses of species to a changing climate. The project used two flagship butterflies that inhabit two of California's most prized ecosystems—oak savanna and native grassland—to study if species with differing characteristics differ in the extent to which their populations are adapted to local climates. Determining the extent of such local adaptation is critical to understanding the large-scale responses of organisms to climate change—specifically, the changing boundaries of species' distributions. For both species, results reveal genetic differentiation of northern (British Columbia) and southern (San Diego County) populations from the rest of the study populations. The divergence of northern populations suggests the potential for local adaptation, a factor that could reduce, slow, or eliminate poleward range expansion under climate change. The southern populations are likely to decline under climate change as conditions become unsuitable; therefore, genetic diversity that occurs there may be at risk.
- *Biological Impacts of Climate Change in California (BICCCA).* Terry Root (Stanford), Jill Talmage (PRBO). This is the second phase of an on-going PIER effort to study the biological impacts of climate change and to develop long-term conservation plans in consideration of the effects of climate change. Individual studies under this project include: using the fossil record to reveal how California mammals may respond to continued climatic change; effects of changes in the pattern of snowmelt on bumblebee communities in the Sierra Nevada; climate change impacts on invertebrate prey (mesozooplankton) for important higher trophic level predators in the California current; effects of climate change on the elevational distributions of bird species in southern California; effects of elevated atmospheric CO_2 on the physiology of the purple sea urchin; changing rainfall patterns and grassland biodiversity: climate change impacts from individual to ecosystem scales.
- *Grinnell Resurvey Project.* Mortiz (UC Berkeley). Researchers are testing ecological models designed to estimate changes in flora and fauna using the unique Grinnell survey data, the largest and oldest (early 20th century) historical survey database on small mammals and birds. The research team repeated a detailed, early 20th century survey of small mammal diversity across a 3000 m elevation gradient spanning the long-protected landscape of Yosemite National Park, and found substantial (500 m on average) upward changes in elevational limits for half of the 28 species monitored. Ranges of formerly low elevation species expanded and those of high elevation species contracted, leading to changed community composition at mid and high elevations. An important finding of this

study was that responses were idiosyncratic among closely-related and ecologically-similar species, altering elevational patterns of replacement under directional climate change. This is not what the species distribution models would have predicted.

- *Collection of Ecological Data for Climate Change Studies.* RFP In Process. The selected studies will initiate or continue ecological monitoring programs that can provide data for modelers and others studying the ecological impacts of climate change. PIER is interested in resurvey-type studies in particular that can provide important information for the evaluation of models, climate change detection studies, and for climate impact studies.

6.0 Gaps in Research/Knowledge Relevant to California

To date, the PIER-EA research on ecology and adaptation as outlined above has been designed to focus on assessing impacts/vulnerability of future changes in temperature and precipitation on the ecological systems and species in California. At this time, there remain gaps in our knowledge with respect to species/natural systems vulnerability information and the information needs of natural resources managers for decision-making in the management of species/natural systems for adaptation. Because the process of developing adaptation strategies and resilience in ecological systems is necessarily based in decisions regarding natural resource management, a more complete research process is needed that addresses both the ecological and the social aspects of adaptation of natural systems. Thus, it is critically important that research explicitly:

- Addresses management goals and management targets of relevant state agencies
- Fully recognizes the information needs of resource managers that manage species and natural systems for addressing goals
- Provides guidance on use of vulnerability information to achieve management goals, including guidance on information interpretation with respect to range uncertainty of outcomes and managing risk
- Fully identifies and addresses the steps of an adaptation framework for resource management decision-making
- Defines set of standard impact assessment methodologies including defining which general circulation models and which emissions studies most appropriately applied to California and most reasonably bound the range of future climate outcomes
- Conducts climate impacts/vulnerability modeling at relevant spatial and temporal scales to capture the biological processes of concern and scale of management
- Develops adaptation strategies and associated costs for decision-making
- Develops a body of information that is readily accessible to resource managers and decision makers

Moving forward, research should continue to address the Impact/Vulnerability questions (e.g., what are the species/system vulnerabilities, what are the synergistic stressors?), but also begin to address the management Adaptation Research questions (what can be done to increase resilience of natural systems, what can be done to prepare for the unavoidable and uncertain future impacts/ how can that be done most cost-effectively, and how should it be done to increase system resilience and minimize the loss?) Detailed general areas of the full adaptation research agenda with brief descriptions are provided below:

Impacts/Vulnerability Research

- *Monitoring for change and developing data availability at management scales:* In general, it will be important to obtain a focused elicitation of the ecological properties or components needed to reach management goals and to identify baselines for those properties with monitoring programs to assess change.
- *Improving understanding of vulnerability across relevant targets for management of resources:* To date much of the research on vulnerabilities has focused on employing process-based models like the DVMs or species distribution models like BioMove. While both are critically important, species and processes are inextricably linked. Since changes in vegetation are often catalyzed by process-based disturbances such as wildfires that affect habitat suitability for animal species, there is a need to translate dynamic shifts in the spatial distribution of the vegetation into future habitat availability for wildlife species of concern and their dispersal capabilities.
- *Improving understanding of multiple, interacting stressor influences on vulnerability of the species/system of concern:* It is clear from previous research that multiple interacting stressors can significantly enhance the impacts of climate change on the vulnerability of natural systems. Understanding these impacts and the management capacity to abate the interacting stressors is critical for long-term adaptive management of resources. Indeed, it may be necessary to define the management scale beyond the boundaries of a single habitat type, management area, or political or administrative unit to encompass an entire ecosystem or region. Currently, management plans for forests, parks, and other managed areas are often developed for discrete geographies with specific attributes. Research needs to explicitly address that management areas are nested in broader spatial context that may alter management strategies.
- *Determining distributional/abundance impacts across a range relevant to management:* In the future, as species shift and systems shift in range in response to climate change, managing for particular outcomes at a single place may prove to be futile. Better understanding the temporal and spatial patterns of movement of species in response to climate change will allow for addressing shifting management options in space and time.
- *Understanding vulnerabilities under extreme events:* Ecological investigation of the probability and impact of extreme events combined with managers' expertise with extreme events can reveal strategies for managing natural systems for resilience in the face of major climate-driven disturbance. Under such conditions, priority-setting may involve triage (Metzger, Leemans, and Schröter, 2005). Some goals may have to be abandoned and new goals established if climate change effects are severe enough. Even with substantial focused and creative

management efforts, some systems may not be able to maintain the ecological properties and services that they provide in today's climate. In other systems, the cost of adaptation may far outweigh the ecological, social, or economic returns it would provide. In such cases, resources may be better invested in other systems.

Management Adaptation Research

- *Developing a research process that explicitly engages resource managers in identification and development of research needs:* Vulnerability and adaptation research is often conducted to produce generalized frameworks for adaptation or large-scale vulnerability assessments that are largely inaccessible to or not relevant to resources managers. In developing research activities for climate change adaptation, resource managers should be engaged in the discussion to define the needs to ensure research products are readily applicable and relevant.
- *Developing a body of vulnerability and adaptation information that is readily accessible to resource managers and decision makers:* Scientists and managers across agencies and management systems would benefit from accessibility of data, models, and experiences. It may be necessary to develop formal structures and policies that foster extensive interagency cooperation with the goal of how best to apply knowledge to decision-making.
- *Understanding impact of management action on vulnerability outcomes:* In many cases, management of resources can influence the resources' vulnerability to climate change. In one illustrative example, Pyke and Marty (2004) found that grazing management actually enhanced vernal pool diversity by increasing days of inundation, thus decreasing vulnerability of those vernal species to climate change.
- *Developing approach for understanding vulnerabilities in context of managing risk:* For adaptation strategies to be effective they must result in climate risk being considered as a normal part of decision-making, allowing natural resource managers to reflect their risk preferences just as they would for other risk assessments in the context of strategic planning and risk management. To allow for this climate-modified risk assessment by resource managers, we will need to develop techniques for applying it in practical situations.
- *Developing adaptive strategies to meet the goals, understanding the limits of adaptations strategies, and developing processes to adaptively reassess goals:* To adapt in a changing climate, we need to develop criteria for determining climate change resilience of management strategies, and apply those criteria to a review of current management strategies for their potential application under a changing climate.
    - Identify potential non-traditional policy and regulatory opportunities for mitigating the impact of climate change on biodiversity (e.g., understand current flood control policies and how they might need to be adapted to maximize biodiversity outcomes under a changing climate.
- *Identify opportunities for modifying goals/policies/regulatory frameworks to allow for increasing adaptive capacity:* The scale of the challenge posed by climate disruption

and the uncertainty surrounding future changes demand coordinated, collaborative responses that go far beyond traditional “agency-by-agency” responses to stressors and threats (CCSP, 2008). There is a need for research into the extent to which structures and policies foster extensive interagency cooperation.

7.0 Conclusions and Prioritized Recommendations

7.1 Conclusions

[To be provided.]

7.2 Prioritized Recommendations

PIER funds its research according to the following criteria: (1) relevance to PIER objectives (i.e., concerning the energy sector); (2) likelihood of generating scientifically and/or policy-relevant results within no more than four-to-five years; (3) potential applicability to California policy-making related to climate change; (4) technical quality and potential to advance scientific understanding; (5) potential to generate “co-benefits” (i.e., in science or policy not directly related to climate change); (6) likelihood of eventually securing co-funding from other agencies; and (7) the clear need for state support to reach the level of funding necessary to address these issues adequately. The research topics identified here are a result of interviews and discussions with scientists, government officials, and natural resource managers.

Impacts/Vulnerability Research

- *Monitoring for change and developing data availability at management scales*
    - Develop monitoring programs to establish baselines and test effectiveness of adaptation strategies.
    - Develop regional climate models parameterized for California for use in impact/vulnerability studies at scales relevant to management.
    - Test modeled range shifts with historical and current species observations, and monitoring plans for areas where species are predicted to be extirpated.
    - Historical validation of AOGCM performance in California, with climate variables that are relevant to resource management (e.g., t_{max} in the summer, t_{min} in the summer, evapotranspiration, seasonality of precipitation).
    - Use historical baseline observational data and species modeling to calibrate and test projections about climate change impacts on species distribution and abundance in the future.
- *Improving understanding of vulnerability across relevant targets for management of resources*
    - Develop methodologies to integrate process-based and species-based models and apply them to California management areas.

- *Improving understanding of multiple, interacting stressor influences on vulnerability of the species/system of concern.*
    - Develop impact assessment of multiple interacting stressors on vulnerability of the state's natural resources, particularly focused on land use change, fire and invasive species and their interaction with species-responses to climate change.
- *Determining distributional/abundance impacts across a range relevant to management*
- *Understanding vulnerabilities under extreme events.*

Management Adaptation Research

- *Developing a research process that explicitly engages resource managers in identification and development of research needs*
- *Developing a body of vulnerability and adaptation information that is readily accessible to resource managers and decision makers*
    - Develop web-based public databases for dissemination of research results and guidance on how to incorporate results into management practice to enhance adaptive capabilities.
- *Understanding impact of management actions on vulnerability outcomes*
    - Conduct an assessment to establish which management practices enhance or decrease species/system resilience under climate change and how each might need to adapt to allow for increasing adaptive capacity.
- *Developing approach for understanding vulnerabilities in context of managing risk*
    - Provide guidance on the use and interpretation of climate change impacts and vulnerabilities assessment, including uncertainty of outcomes, with respect to meeting management goals. Design programmatic outreach to disseminate findings.
- *Developing adaptive strategies to meet the goals, understanding the limits of adaptations strategies, and developing process to adaptively reassess goals*
    - Develop understanding of the implications of hotspots of genetic diversity for meeting long-term biodiversity goals.
    - Develop methodologies and case studies for applying species-specific impact studies to resource planning and implementation.
    - Develop methodologies that prioritize development of protected areas for sustaining existing species across a climatic gradient, incorporate important corridors for species/system movement, and target processes that sustain biodiversity (including evolutionary processes).
    - Develop methodologies to integrate vulnerability information from finer-scale modeling and experiments with the planning-scale methods for the development of short- and long-term priorities.

- Develop methodologies for assessing adaptation costs for alternative conservation strategies and triage criteria.

- *Identify opportunities for modifying goals/policies/regulatory frameworks to allow for increasing adaptive capacity*

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